CAN MEDICAL SCIENCE TEACH CONSERVATION SCIENCE TO BECOME MORE EFFECTIVE?

by
Kimberley Crocker Pearson, MS MD MPH

A capstone submitted to Johns Hopkins University in conformity with the requirements for the degree of Master of Science in Environmental Sciences and Policy

Baltimore, Maryland
May, 2020

Table of Contents

Executive Summary

In the United States, most conservation decisions are delegated to local governments and agencies. Those decisions are made by appointed or elected officials who have minimal or no training in conservation science. Researchers aspire to have these decision-makers utilize scientific evidence in their work, yet the type of evidence that would best support decision making - i.e., the effectiveness of interventions in the real world - is significantly underrepresented in the conservation evidence literature. Scarcer still is any representation of the comparative effectiveness of different strategies that are designed to reach the same conservation goal.

In contrast, over the past fifty years, the medical profession has integrated the collection and use of "real-world" data and evidence on the effectiveness of therapies into day-to-day medical practice. This process has been facilitated by the development of standardized outcome measurements, both disease-specific and generic, that are routinely collected from both clinical trials and clinical encounters. Conservation scientists have thus far been unable to develop such outcome measurements. Instead, they remain divided as to whether ecocentric or anthropocentric measures are the best indicators of conservation effectiveness.

During the past two years of study in environmental science and policy, this conflict between the interests of human communities and those of their natural environment has been the central theme for every discipline in the JHU Environmental Science and Policy curriculum. In Ecology, the effects of human-caused habitat loss on biota are a main focus. In Hydrology, we study the effects of the built environment on local flooding or drought conditions. And, in our

studies of environmental policies, the overriding tensions are between the effect of human demands for goods and services and the degradation of landscapes and their diverse biota.

One way to resolve this debate is to utilize "win-win" outcome measures of conservation initiatives in which benefits to both humans and ecosystems are measured as co-equal outcomes. Effectiveness evidence collection can be accomplished without major expense through collaborations between paid scientists (“professionals”) and trained (unpaid) “amateur” scientists utilizing recent technological advances. When such collaborations are designed by scientists utilizing methodology to assure data validity and minimize bias, they can be invaluable additions to the use of evidence in conservation policy decision-making.

Introduction

The motto "Think Global, Act Local" is variably attributed to Patrick Geedes, a Scottish scientist of the early 20th century. Geddes was a polymath; a biologist and groundbreaking town planner who made significant contributions to the inclusion of environmental integrity in the planning of human communities (Boardman, 1978). Were he here today, Geddes would likely teach us that solutions to our global environmental crisis lie in the local conservation actions of communities at the scale of their bioregions (Wahl, 2017).

In the United States, land-use on private property is a critically important component of conservation strategy (Jenkins et al., 2015). As of 2020, approximately 72% of the land in the United States is privately owned (Vincent et al., 2017). The prevalence of private ownership in the United States places the responsibility for biodiversity conservation in the hands of hundreds of millions of individual land owners. (Moon, 2011) In the United States, local governments possess the most direct powers to regulate private land-use (Porter, 2012)[1], meaning that in the United States, approximately 75% of land use decision-making occurs primarily at the lowest government level (Theobald et al., 2000). (Figure 1) Local land-use decisions are a critical component of a global sustainability strategy, as they have the potential to impact conservation goals and adversely affect ecosystems. Because of their importance, it is important to consider who makes these decisions.

[1] In the 1920s-30s, states gave local governments authority to regulate land use through use of the police power of the Tenth Amendment: "protect health, safety, and general welfare of citizens" (*10th Amendment US Constitution--Reserved Powers*, n.d.). Local governments are closest to people and lands being regulated. The right of local government to regulate land use has been upheld numerous times by the supreme court (Porter, 2012).

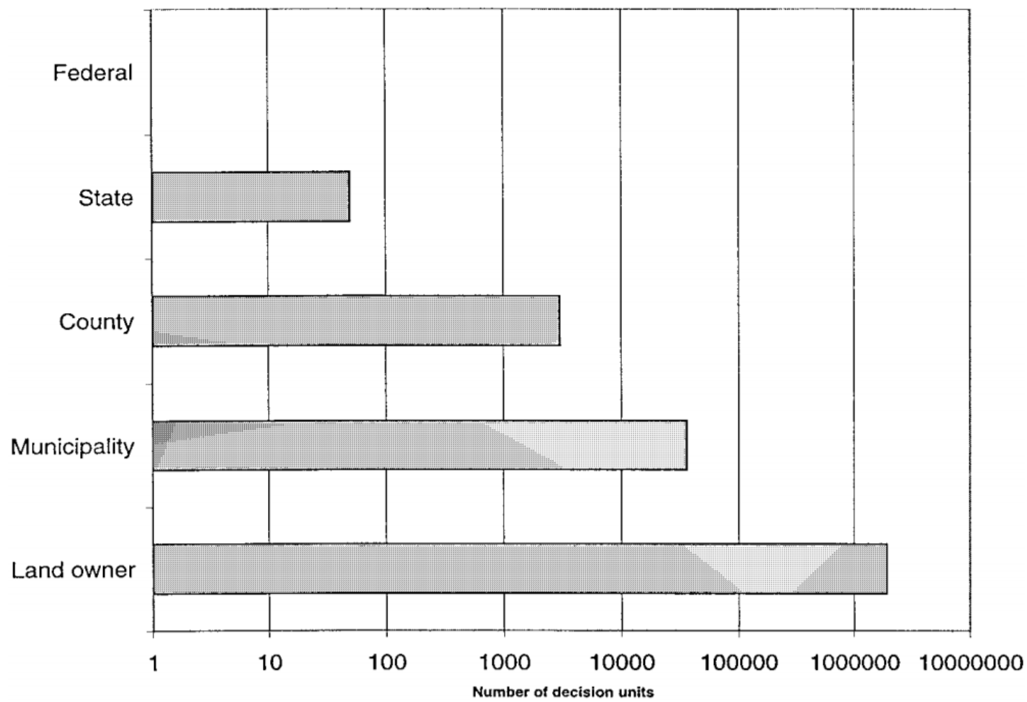


Figure 1: Land Use Decision Making Hierarchy in the United States.[2]
This shows the number of jurisdictions (decision making units) with legal authority for making land use decisions.

The process of land-use change In the United States begins with petitions at the local level which are presented by landowners to zoning boards, boards of health, conservation commissions, and, in some cases, specialty departments such as wetlands or coastal commissions. In most small towns, decision-makers are rarely, if ever, trained in or advised by professionals in conservation science. They are charged solely with deciding whether the requested land-use change fits within existing regulations; or, failing that, whether the issuance of a variance to the regulation is warranted.

In most cases, it is not possible to predict the effects that these local land-use decisions will have on the environment. Despite recurring calls from the scientific community for

[2] (Theobald et al., 2000)

policymakers to produce evidence-based policies, researchers themselves, while producing high-quality scientific studies, generally have fallen short in addressing the questions most important to societal decision makers, (Brewer & Stern, 2005) leaving them to rely largely on experience and opinion rather than learning from and adapting their practice based on the effectiveness of their actions.

Conservation biologists have three tasks: first, to identify the causes of biodiversity erosion and second, to recommend strategies to slow or reverse it (Soulé, 1985; Sodhi et al., 2011). The third task is to advise policy-makers on conservation actions to bring about species recovery (Arlettaz et al., 2010). This last task cannot be accomplished without clear evidence of the effectiveness of existing conservation strategies (Sutherland et al., 2004; Ferraro & Pattanayak, 2006). Despite a need for effectiveness data, conservation science research studies rarely incorporate real-world evidence (Godet & Devictor, 2018). Until such information is made readily available in a format that can be utilized by the non-scientist decision-maker, the transition from experience to evidence-based conservation policy is unlikely to occur at the local government level in the United States.

The good news is that conservation scientists have a path to follow for achieving effectiveness in their practices; one that has been charted by medical science. In the early 1960s, local doctors were in a similar place as local conservation managers have been with respect to evidence-based decision making. At that time, those doctors determined what treatments to provide largely based upon education, experience, expert opinion, and even tradition; this was the so-called “art of medicine." A change occurred, however, during the 1970s-80s with the rise of evidence-based medicine and clinical epidemiology, a branch of medicine that tracked the comparative effectiveness of treatments.

Conservation scientists who have followed the process that led to the transition to evidence-based medicine have driven recent developments in their field. However, the concept of comparative effectiveness, an extension of the principles of evidence-based medicine, has been slow to permeate conservation science. Comparative effectiveness evidence for conservation initiatives would be invaluable for local conservation managers, where the wise use of limited fiscal resources has the greatest impact. In these areas, conservation initiatives often involve private landowners who need to be convinced of their cost-effectiveness or may involve special tax levies on the local citizens to support public initiatives. Citizens must be able to trust that decision-makers are using their hard-earned money in the most effective way possible.

The trend toward the use of comparative effectiveness of medical interventions is strongly associated with the incorporation of real-world data into the process of improving patient care and outcomes. The collection of real-world data in conservation could similarly improve the effectiveness of conservation initiatives. This paper presents an explanation and demonstration of how conservation science can continue to learn from medicine and incorporate comparative effectiveness studies into their practice. This may be best accomplished through the use of existing resources such that evidence can both be used and developed in the process of implementation of local conservation initiatives.

Methods

Part 1: Literature Search

The first part of the study consisted of a comprehensive qualitative literature search. The Johns Hopkins University Library, PubMed, and Google Scholar online databases were queried using the search terms "evidence-based medicine", "evidence-based conservation" "healthcare effectiveness", "conservation effectiveness". Returned manuscripts were compiled in a database and sorted by keywords. Citations within those articles were searched to identify additional pertinent references, including book chapters. Articles citing those manuscripts were searched to identify additional references.

Part 2: Demonstration project

Overview: This demonstration project will explore the potential for citizen scientists to be an integral part of the collection of effectiveness data for conservation interventions at the local scale. The research question is: Can a researcher-designed protocol for data collection be implemented by a group of trained volunteers to produce high validity evidence for the effectiveness of different types of coastal erosion-control technologies? Data collection will need to continue for approximately two years to complete the study.

The study site is in the town of Brewster, Massachusetts, where local conservation and coastal commissions are responsible for making conservation land-use decisions. Two indicators will be used to measure effectiveness; one anthropocentric and one ecocentric following a "reconciliation ecology" design. From the human perspective, the indicator will be the loss of shoreline in feet perpendicular to the coastline. From the ecocentric perspective, we will track signs of the Piping Plover, *Charadrius melodus* (Ord, 1824) nesting sites on the restored coastal dunes habitat.

Background: One decision that is frequently faced by the Brewster Conservation Commission is the permitting of erosion control technologies by beachfront homeowners and businesses. For reference, Cape Cod is a peninsula extending 65 miles (105 km) from the coast of Massachusetts into the Atlantic Ocean, with more than 400 miles (640 km) of shoreline. Like much of the coastal United States, sea-level rise and climate change have increased the rate of coastal erosion over the past few decades. The impacts associated with coastal erosion for humans include property loss, infrastructure damage, and beach loss but there is also habitat loss for shoreline species.

Figure 2: Massachusetts map showing Cape Cod and the islands at the right (Basemap Source: Freeworldmaps.net)

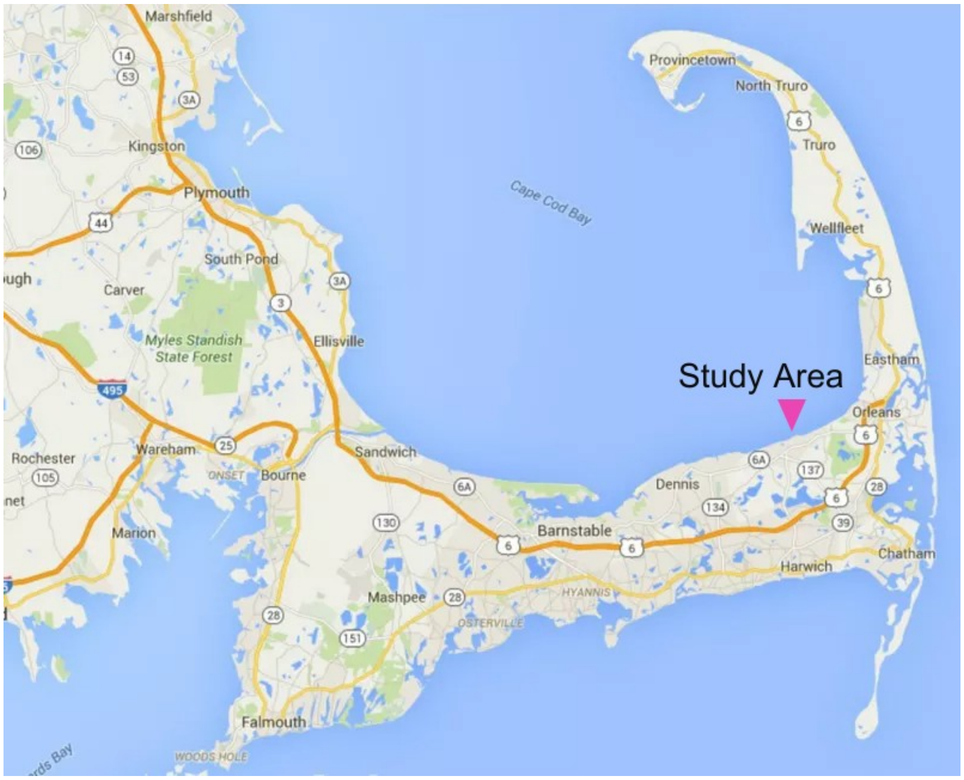


Figure 3: Cape Cod with study area indicated
(Basemap Source: Google Maps)

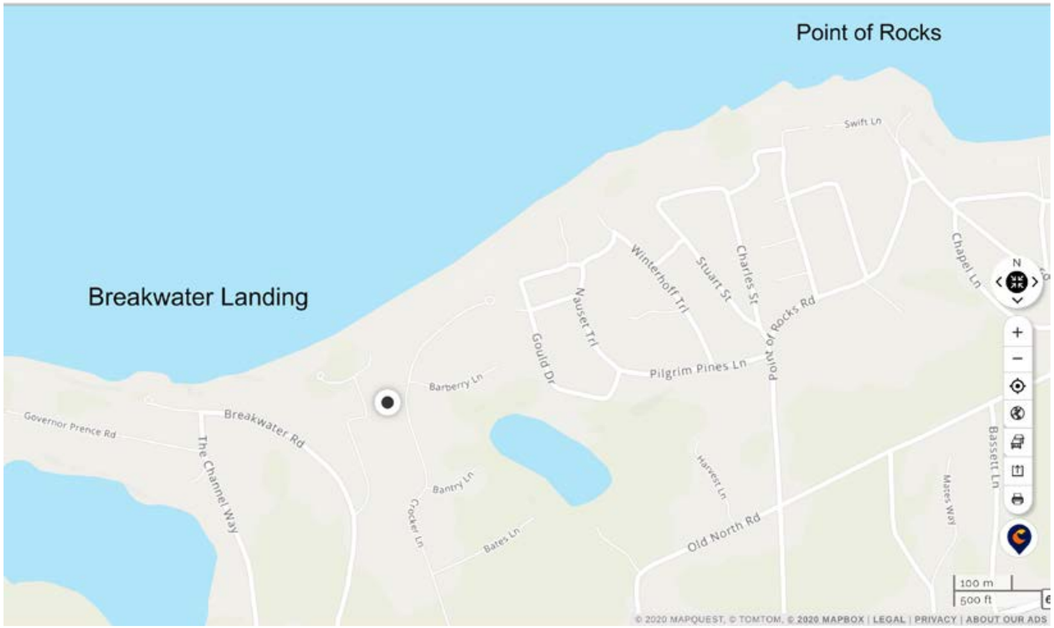


Figure 4: Extent of Mapped Coastline - Breakwater Landing to Point of Rocks
(Basemap Source: MapQuest)

Options for the management of coastal erosion include armoring of the shoreline, replenishment of beach sediment, and relocation of threatened structures. Shoreline armoring can be effective at preventing land loss due to chronic erosion but can often have deleterious impacts on the natural environment, including loss of beach sand, coastal vegetation, and habitat. One strategy, *beach nourishment* involves adding sand to the beach system to combat erosion. *Shoreline retreat* entails relocating coastal buildings and infrastructure landward (or simply demolishing structures) to allow coastal landforms to evolve over time. While this strategy could seem reasonable from the perspective of the environment, loss of private buildings and land motivates strong opposition to this type of approach among landowners, especially those near the shoreline and in highly erosive environments. Local government officials also frequently frown on this approach, due to loss of infrastructure and property tax revenue and the potential impacts on the economy. Significant political pressures usually prevent serious consideration of shoreline retreat.

Several additional options exist under the categories of "hard" and "soft" erosion control modalities. Soft solutions may include fabrics, coir envelopes, and sandbags. Hard solutions include rock, concrete, and steel, which may increase the risk of damage due to adjacent areas due to wave reflection off of such hard structures. Rock structures, such as revetments, walls, and breakwaters are traditional approaches to shoreline protection and initially provide adequate protection against strong storm conditions, however, these structures ultimately accelerate erosion due to increased wave reflection and/or the interference of these structures with natural shoreline processes. Because of these concerns, there is a growing tendency toward the use of "soft" technologies to stabilize beach erosion which use biodegradable materials, such as jute and others. Recently, the most common technology utilizes coir, a fiber extracted from the husk of the coconut which can be made into envelopes which are then filled with local beach sand and built into terraces that extend up the face of the coastal bank. These soft materials absorb wave energy and help encourage sand to accrete naturally, further reducing wave reflection. Coir envelopes can also be planted with beach grass and other local vegetation to restore coastal banks and provide habitats for birds and wildlife (Lager, 2016).

Management of coastal erosion is at its core a land-use issue for local conservation practitioners who must rule on permissions for the placement of shore-hardening modalities on private property. Massachusetts coastal regulations, in part, prohibit armoring active coastal dunes, however, for older structures, armoring is still permitted despite the negative conservation impact. When facing decisions on beach armoring, the Conservation Commission would prefer to endorse soft armoring but some property owners argue that hard structures are "better" for erosion control even though they are known to adversely affect ecosystems.

A threatened species, the Piping Plover, *C. melodus*, nests in coastal dunes. The Piping Plover is a small shorebird that has been greatly affected by human activity over the last few decades. Despite recent efforts to preserve their habitats, these birds are now considered

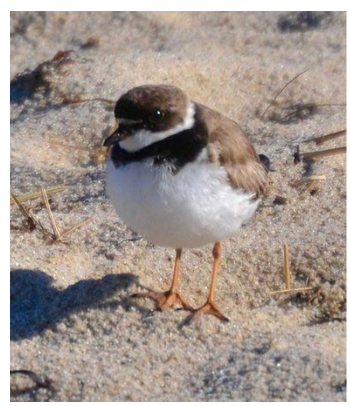


Figure 5: Piping Plover (*C. melodus*)
(Source: Audubon)

a threatened species in all parts of their range due largely to human disturbance. Piping Plovers inhabit sandy beaches and tidal flats because they prefer to nest in open sandy locations near water (Audubon, 2018).

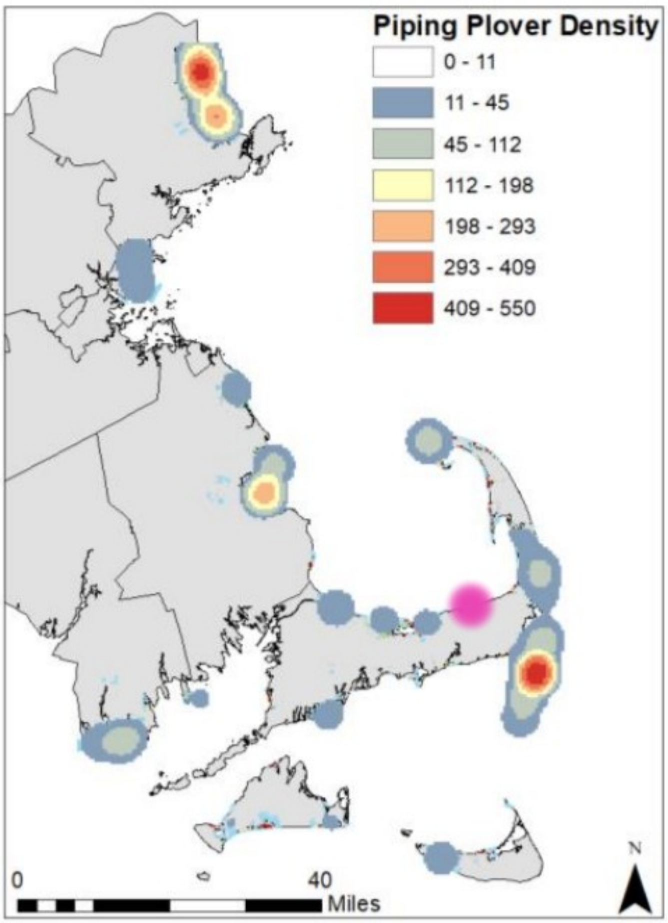


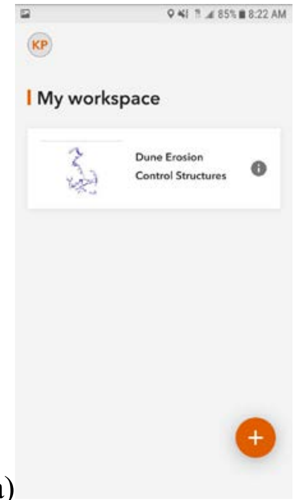
Figure 6: Density of Piping Plover populations around Cape Cod. The magenta dot represents the area under study in Brewster, Massachusetts. At the time of this study, there had been no Plovers reported from the Brewster area for nearly 10 years
(Source: Wang and Bush, 2018).

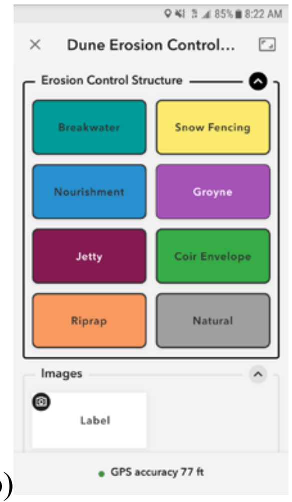
One hypothesis is that soft armoring by rebuilding dunes would preserve or restore Plover habitat which could lead to a restoration of the species numbers in the area. This would be defined as the effectiveness of a human-ecosystem "win-win" conservation project. It may take several years to demonstrate the comparative effectiveness of both the erosion control and biodiversity restoration aspects of coastal erosion control technologies. The goal of this project is to demonstrate the feasibility of the method.

There were no comparative effectiveness studies found that compared hard and soft armoring in a given location. Were data to exist suggesting that the two strategies were similarly effective over a given period, conservation managers would be in a position to rule against hard armoring, thus maximizing the conservation effectiveness of their decision.

Coastal erosion mitigation projects have been increasing in number over the past decade on Cape Cod. Because most of these projects occur on private lands and are permitted on a town-by-town basis, a comprehensive database of the nature, location, and effectiveness of these projects have yet to be established. For this demonstration study, ArcGIS QuickCapture[3], a citizen-science method for collection of comparative effectiveness data among different approaches to erosion control was developed and deployed in the town of Brewster, Massachusetts.

[3] ArcGIS is a product of ESRI (https://www.esri.com)

(a) 

(b) 

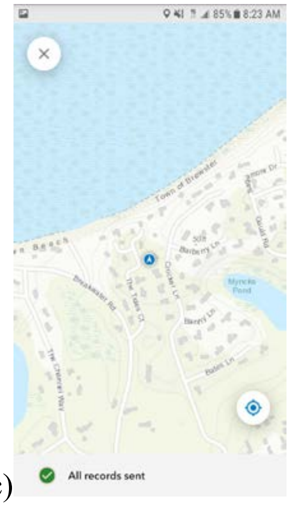
(c) 

Figure 7: QuickCapture App for Data Collection. (a) Shows the opening screen on an Android device. The project dashboard is accessed by tapping on the “Dune Erosion Control Structures” icon. (b) Shows the data collection dashboard. Upon arriving at the beach, the volunteer identifies whether an erosion control structure is present. If yes, the correct button is tapped and the volunteer walks along the beach for the length of the structure. When they reach the end of the structure, they stop and tap the same button again, ending the data collection. If no structure is present, the area is mapped as “natural.” After the button is tapped the second time, the data are automatically uploaded from the phone to the ArcGIS Online map where they can be seen by the investigator. (c) Data upload is documented on the app.

The existing erosion control structures along the Brewster (Massachusetts) shoreline between Breakwater Landing and Point of Rocks were identified and mapped. Utilizing ArcGIS, a mapping layer was built to receive data from a QuickCapture app that was designed for this project. Data were collected from a stretch of beach in Brewster, Massachusetts along which a variety of erosion control technologies have been deployed. The location and extent of each technology were mapped and this layer was superimposed on layers produced by the MassGIS Bureau of Graphic Information showing the location of the top and toe of coastal banks over time as well as transect measurements of erosion along the shoreline.

In addition, observations were made of any evidence of activity by the threatened species Piping Plover, *C. melodus*, along the shoreline. Indication of nesting activity was photographed, geocoded, and added to the map. The mapping was carried out by myself and a series of trained volunteers. For the demonstration project, I checked all of the observations made by volunteers.

Results

Evidence-Based Medicine

The aim of evidence-based medicine is to integrate the experience of the clinician and the patient, with the best available scientific information into the decision-making process in clinical care (Evidence-Based Medicine Working Group, 1992).

The process of evidence-based medicine: Figure 2 summarizes the path taken from experience to evidence-based medicine. In "Evidence based medicine—an oral history," Dr. Iain Chalmers, cofounder of the Cochrane Collaboration, described his experience as follows: "...like every other (medical) student (I) was filled full of facts to regurgitate in examinations" (Smith & Rennie, 2014). He determined that he wasn't given the tools to find out what worked, and "in retrospect," he said, "I'm angry about that" (Smith & Rennie, 2014). In the early 1970s, Chalmers determined developed a database of perinatal research studies looking for evidence of benefit from the increasing number of interventions in obstetrics and could not find any (Smith & Rennie, 2014).

The first step in the development of evidence-based medicine was the recognition that all evidence is not created equal. In the late 1940s, medical researchers began to use randomized clinical trials (RCTs) to determine the efficacy of new drugs, replacing anecdotal reports from clinical practice observations which could give misleading information (Corrigan-Curay et al., 2018). (Figure 8: "Evidence Generation") RCTs occupy a position at the top of the hierarchy of evidence, followed by other types of studies used to generate medical research evidence. (Figure 8)

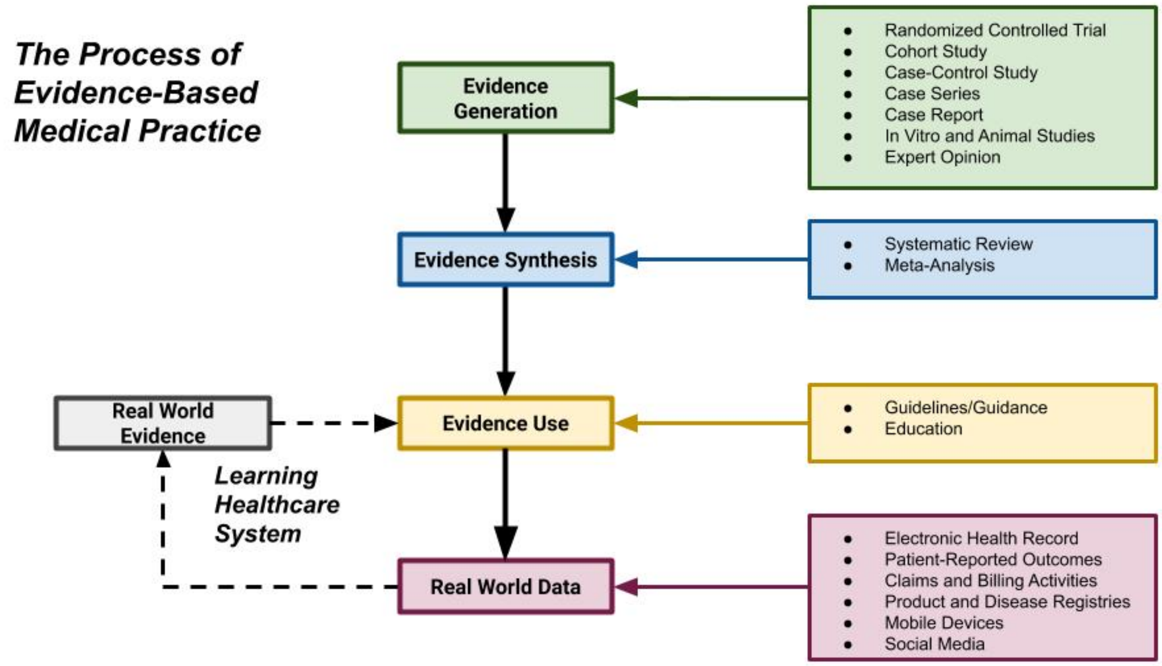


Figure 8: The process and practice of evidence-based medicine

In 1991, Guyatt introduced the term "evidence-based medicine (EBM)" (Guyatt, 1991), by which he meant that doctors should be searching the medical literature for studies with applicability to the conditions of the patients they were treating, determining the quality of those studies, interpreting the results and applying them to to their everyday practice (Evidence-Based Medicine Working Group, 1992).

It quickly became clear that an examination of the totality of the medical research evidence on a given topic was beyond the scope of the daily practice of the average clinician. The solution was the next step on the path to evidence-based medicine; the production of systematic reviews that summarize the best available evidence (Djulbegovic & Guyatt, 2017). (Figure 8: "Evidence Synthesis") A systematic review is a method of performing a review of the literature either qualitatively, or by combining the result of multiple studies using statistical methods (Kaefer et al., 2019).

The Cochrane Collaboration based in the UK is responsible for the biggest advances in systematic review methodology (https://www.cochrane.org). Named after Archie Cochrane, a visionary who proposed that the medical profession organize a "critical summary, by specialty or subspecialty, adapted periodically, of all relevant controlled trials," the Cochrane Collaboration has marshaled over 37,000 collaborators from more than 130 countries devoted to conducting systematic reviews (Djulbegovic & Guyatt, 2017). The application of systematic reviews to the practice of medicine has resulted in major changes, including helping to overturn decades-old erroneous advice that infants should not sleep on their backs, and thus preventing sudden infant deaths (Gilbert et al., 2005). (Figure 8: "Evidence Use") Guidelines and guidance documents, based upon the results of systematic reviews, made evidence-based practice feasible for local doctors.

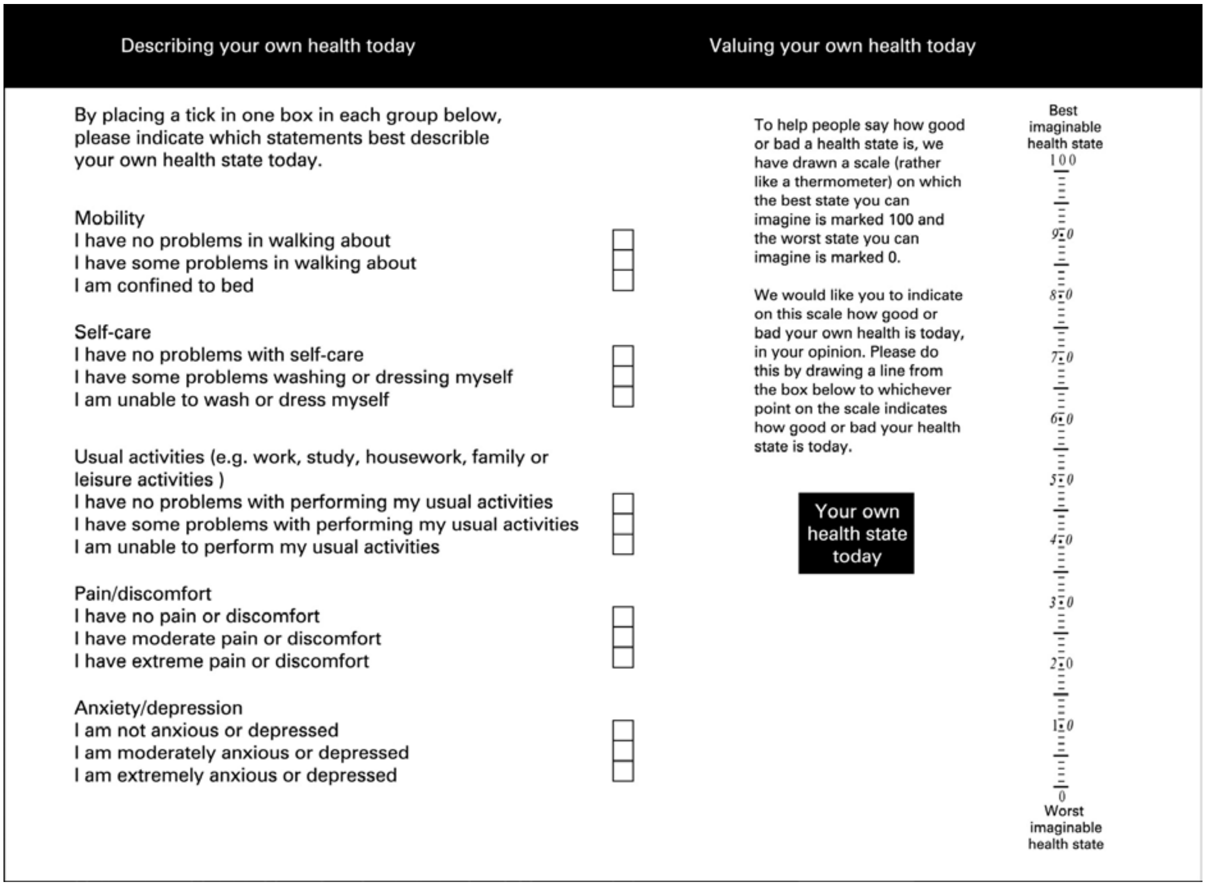
The rise of effectiveness in medicine: Most would agree that the essential purpose of physicians in society is to provide care that improves or maintains the quality of life, as well as extending life itself. Although many clinical studies, including prospective, randomized clinical trials, examine the effects of different treatments or treatment versus no treatment, most fail to analyze how **effective** those treatments are, i.e. will the outcomes of this treatment improve a person's quality of life.

Before discussing the path to effectiveness in medicine, it is important to define and delineate **efficacy** from **effectiveness** as outcome measures in research studies. Different types of evidence are derived from different types of research trials. Medical research trials are conducted to determine the **efficacy** and/or **effectiveness** of interventions. **Efficacy** denotes the ability of an intervention to produce the expected result under controlled circumstances. while **effectiveness** refers to its result under 'real-world' conditions; that is, use or application of an intervention by practitioners without distinctive expertise or experience with the intervention, under the full range of practice conditions and sites. In **efficacy** or **explanatory trials**, the whole experiment is designed to control for all known biases and confounders, so that the intervention's impact is clearly shown. Interventions may be compared with a placebo or with other active treatment in explanatory trials (Kim, 2013). **Effectiveness trials** or **pragmatic trials** are designed to test interventions in the full spectrum of everyday clinical settings which facilitates a determination of the applicability and generalizability of the intervention and its outcome. Researcher as the question: “is whether the intervention actually works under real life conditions?” The study intervention is evaluated against others of the same or different type as they are utilized in regular clinical settings. **Pragmatic trials** measure a wide spectrum of outcomes, from the objective and biological to the subjective and patient-centered (Kim, 2013).

One approach to evaluating the effectiveness of medical interventions is to collect data as a routine part of medical practice; sometimes referred to as “Real-World Data (RWD).” (Figure 2) These data can be derived from patient information collected in two different ways: passive or automated and active or patient-reported. A large volume of electronic information is collected by a variety of sources as part of the practice of medicine and this has generated a large volume of RWD. These sources include primary and secondary patient care records such as those in electronic health records (EHRs), insurance claims data, routinely collected administrative data, product and disease registries, and emerging observational sources such as social media and data collected from mobile devices and apps. RWD is used to generate "Real-World Evidence (RWE)", which is information about the use and benefits or risks of a medical treatment that is derived from an analysis of RWD. (Figure 8)

Administering patient-reported outcome questionnaires allow healthcare providers to know whether the treatment is **effective** in achieving results that improve the quality of life in an individual patient. For example, suppose a treatment improves a randomized control trial treatment population's visual acuity from 20/30 to 20/25. There is an objective measurable change in vision, but is this change perceived by patients in the real world as improving their quality of life? Several questionnaires have been developed to collect this type of data of which the EQ-5D is the most well-known and widely used health status instrument (Räsänen et al., 2006). (Figure 9) Since its development, the EQ-5D has been incorporated into clinical trials, observational studies, and population health surveys and has thus become part of the 'big data' of medical care (Devlin & Brooks, 2017).

The EQ-5D is referred to as a generic instrument in that it can be used for all medical conditions and treatments. This allows for comparisons of the effect of any treatment on the health-related quality of life of an individual suffering from any disease. It also allows for comparisons of improved quality of life among different diseases and patient groups. Because of its generic nature and ease of self-administration, the EQ-5D has been used to acquire over a quarter-century of effectiveness evidence in healthcare (Devlin & Brooks, 2017)**.** Disease-specific instruments in which questions are tailored to specific symptoms of that disease also exist which provide treatment effectiveness data for a specific medical condition. Often, specific and generic instruments are used in combination.


Describing your own health today

Valuing your own health today

By placing a tick in one box in each group below, please indicate which statements best describe your own health state today.

Mobility
I have no problems in walking about
I have some problems in walking about
I am confined to bed

Self-care
I have no problems with self-care
I have some problems washing or dressing myself
I am unable to wash or dress myself

Usual activities (e.g. work, study, housework, family or leisure activities)
I have no problems with performing my usual activities
I have some problems with performing my usual activities
I am unable to perform my usual activities

Pain/discomfort
I have no pain or discomfort
I have moderate pain or discomfort
I have extreme pain or discomfort

Anxiety/depression
I am not anxious or depressed
I am moderately anxious or depressed
I am extremely anxious or depressed

To help people say how good or bad a health state is, we have drawn a scale (rather like a thermometer) on which the best state you can imagine is marked 100 and the worst state you can imagine is marked 0.

We would like you to indicate on this scale how good or bad your own health is today, in your opinion. Please do this by drawing a line from the box below to whichever point on the scale indicates how good or bad your health state is today.

Your own health state today

Best imaginable health state

100
90
80
70
60
50
40
30
20
10
0

Worst imaginable health state

Figure 9: An example of an EQ-5D Health-related quality of life questionnaire. [4]

Using real-world evidence of effectiveness to improve healthcare: Patient-reported outcome indicators, like those collected by the EQ-5D, and other forms of real-world evidence can provide feedback on the effectiveness of treatments on a shorter timeline and for less cost than research trials.(Swift et al., 2018) This RWE can therefore be rapidly incorporated for use in the evidence-based medicine process (Figure 8) to improve effectiveness in medical practice. This results in what has been called a "Learning Healthcare System."

Learning Healthcare Systems are based on a cycle that generates and applies the best evidence to ensure innovation, quality, safety and value in healthcare (Mullins et al., 2018). They

[4] Euroqol Health Group

consist of an organizational structure in which patients, healthcare professionals and researchers collaborate to produce and use data. These systems produce large electronic real-world data sets, *i.e.*, "big data," collected on individual patient encounters. While these data are largely driven by the healthcare professionals, patient-reported data are also collected. With the support of technology, these real-world data are analyzed, evidence is produced, which is incorporated into practice leading to improved clinical practice Subsequently, new patient data are collected and the cycle continues (Forrest et al., 2014; Taylor, 2008; Deeny & Steventon, 2015; Abernethy et al., 2010).

This type of learning system would meet the goals of local conservation managers. By receiving feedback on conservation practices from both an objective perspective as well as a human perspective, resources could be targeted to areas where they will be most effective.

Evidence-Based Conservation

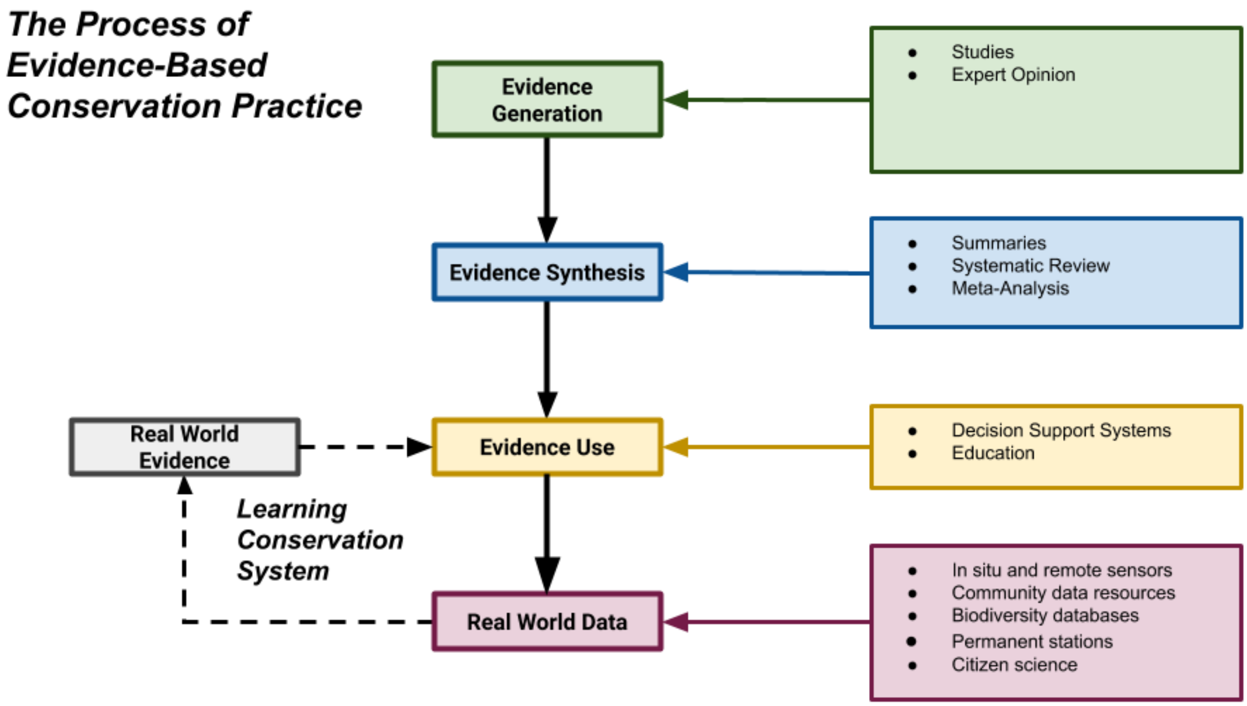


Figure 10: Proposed process of evidence-based conservation practice

In the early 2000s, it was shown that conservation practitioners, like their earlier physician counterparts, were not relying on the best available scientific information in their everyday work (Pullin et al., 2004; Pullin & Knight, 2005). Consequently, conservation decisions were mostly based upon experience and expert opinion rather than a critical appraisal of the evidence of efficacy of different strategies (Pullin & Knight, 2001; Pullin & Knight, 2003; Sutherland et al., 2004). The repercussions of not using evidence-based practice could include ineffective or even harmful conservation initiatives and poor decisions on the allocation of limited conservation funding (Maestre Andrés et al., 2012; Hayward et al., 2019). The limited use of scientific information in conservation practice was attributed partly to decision-makers' lack of access to relevant scientific literature, and to a lack of effort to synthesize the evidence base into decision support systems (Pullin & Knight, 2003).

Following the Cochrane Collaboration example, the Conservation Evidence Project (CEP) was established as a platform for amalgamating systematic reviews of research studies. (http://www.conservationevidence.com) Based at the University of Cambridge in the UK, the CEP has a simple yet ambitious aim; to develop a comprehensive database of conservation interventions undertaken around the world, and synthesize the evidence on their efficacy. They produce 'Conservation Evidence Synopses' which include collations of global evidence from systematic reviews to inform policy or set research priorities (Sutherland et al., 2019). Each scientific paper is summarized in a single paragraph, and the key messages are extracted from all papers to provide a quick overview of the topic. A map shows the location of the studies on that intervention globally, and experts review the evidence and score every intervention for its effectiveness, the certainty of the evidence, and any harmful side effects, placing each intervention into a color-coded category from 'beneficial' to 'likely to be ineffective or harmful (Dicks et al., 2014).

The Collaboration for Environmental Evidence (CEE), is another organization that performs conservation evidence synthesis. They have completed a range of systematic reviews looking at evidence of effectiveness and impact of some types of conservation interventions. All of the CEE SRs completed to date have concluded that sufficient evidence to inform future decisions is lacking (Pullin, 2015).

This synthesis of research study evidence is the first step toward evidence-based conservation practice. However, further steps must be taken to incorporate evidence into routine practice. While Conservation Evidence is performing rigorous systematic reviews of research studies, their description of **effectiveness** seems more in line with a measurement of **efficacy**. They state that their metric of effectiveness is: "an assessment by independent experts of the effectiveness of this action based on the summarized evidence (0% = not effective, 100% = highly effective). This score is based on the direction and size of the **effects reported in each study**, " not on an assessment of outcomes when the practice under study is attempted in the real-world (https://www.conservationevidence.com).

Most studies testing conservation interventions, up to 86% in one study, examine a single strategy, usually compared against a control. (Smith et al., 2014) As described earlier, this approach is useful in determining the **efficacy** of an intervention; that is, how it performs under ideal conditions and in exerienced hands.

Just as in medicine, a key step to understanding the effectiveness of conservation interventions is to compare different treatments within studies. **Comparative effectiveness** studies compare results across different conservation interventions simultaneously. (Smith et al., 2018) The direct comparison of multiple management interventions is important because generally, several conservation actions or ways of implementation could be considered for a given location, however, they might not all provide equivalent benefits. Thus, one must go beyond efficacy studies and use comparative effectiveness studies to rank the success rate of different management interventions. (Rannap et al., 2010) Figure 10 shows an aspirational goal for an effectiveness process in conservation science.

Effectiveness for Conservation

An important measure of the effectiveness of a medical treatment is a perceived change that it produces in the patient's health-related quality of life. If conservation science is to follow the path of medical science toward a "Learning Conservation System", there must be a system by which feedback on the effectiveness of interventions can occur on a short timeline. To assess the effectiveness of a conservation strategy, a methodology must be developed by which a change in the “health” of an area under conservation can be observed and measured. On this point, ecologists, conservation scientists, and biologists have significant disagreements.

The idea of a learning conservation system is not new. The term "Adaptive Management" (AM) has been applied to this approach to conservation effectiveness. Similar to a "Learning Healthcare System", AM is a proposed rigorous approach to implementing, monitoring, and evaluating actions, to learn and adjust those actions. (Marmorek et al., 2019) Properly chosen ecological indicators are crucial to adaptive management's four phases: plan, do, check, and adapt. Further, an adaptive approach allows an indicator to be chosen based on current knowledge, then revisited as more is learned.

Adaptive Management treats conservation actions as experiments to monitor and learn from, creating a central role for conservation scientists in constructing the monitoring programs intended to guide learning. (West et al., 2019) If good evaluation study designs are implemented from the beginning of the project, indicators designated and adequately monitored, data analyzed transparently, then there is much to learn from the results. (Pullin, 2015)

The concepts of “health” and “illness” have been applied to ecosystems for over half a century without a clear definition of what they actually mean. (Lutz et al., 1957) Ecologists have long sought concise and cost-effective measures that can characterize the overall condition of an ecosystem. (Rapport et al., 1985; Munasinghe & Shearer, 1995; Schiller et al., 2001; Logan et al., 2020) However, attempts at development of a set of indicators of something resembling human "health-related quality of life"[5] has eluded them. Successive sets of proposed indicators have increased in complexity with respect to both measurement and analysis (Logan et al., 2020), so much so that Lancaster (2000) was moved to state: "Indeed, what methods should or could be used to assess ecological health of the environment? Do existing techniques suffice or are new ones required?" (Lancaster, 2000)

It is understandably more complicated to identify representative indicators of "health-related quality of life" in conservation than it is in medicine. The practice of medicine is essentially limited to the application of specific treatments or interventions designed to improve the health of individuals or populations of a single species, humans. By contrast, conservation is often about balancing many potentially conflicting goals among populations of multiple species in different environments and geographic areas. In ecological systems, the number and variety of variables from one site to another are much greater and controlling for biases and confounders in conservation research is significantly more difficult.

Because we are attempting to emulate developments in human healthcare, perhaps an extension of the medical analogy could be helpful. These questions are a place to begin:

- Data gathered directly from treated patients was integral to the development of a Learning Healthcare System. In conservation science, who is the "patient?"
- Data were gathered using a set of indicators of health-related quality of life. What properties indicate health-related quality of life for the conservation "patient"?
- Learning Healthcare Systems rely on evidence derived from data that are collected automatically or self-reported by patients and are easily analyzed. Can

[5] Health-related quality of life is one aspect of overall quality of life. As measured by questionnaires like the EQ-5D, health-related quality of life can be defined as a patient's self-perceived health status. (Karimi & Brazier, 2016). How this concept can be applied in conservation will be discussed in this paper.

conservation science find simple and easy ways to collect data that can be easily analyzed to reflect effectiveness of their interventions?

These questions are addressed in detail below.

Who is the patient?: The answer to this question in medicine is generally quite clear; however, in some cases, there may be multiple patients that will be affected by the same course of treatment. An easy example is that of a pregnant woman, whose treatment in many cases will have direct impacts on her fetus. In medicine, we are also faced with the question of who should speak for an infant or child, or other individual who cannot communicate their preferences regarding quality of life with their healthcare provider. This question is no less controversial in conservation science than it is in medicine.

The question "who is the patient" in conservation science is akin to the second case above. At the heart of this problem is that conservation scientists tend to fall into "camps" or ethical standpoints when deciding from what perspective conservation efforts should be approached: should we choose the preservation of natural resources for human use (an *anthropocentric* position that supports biodiversity protection primarily for the well-being of humans), or is the protection of nature for its own sake (an *ecocentric* perception that supports biodiversity protection based upon the intrinsic value of nature) a better metric.(Kopnina, 2017) This dichotomy could be stated differently: Are we humans the "patient" whose quality of life is of paramount concern when considering conservation strategies, or is the natural environment the "patient" who's "quality of life" must be considered solely from its own perspective?

The anthropocentric perspective, exemplified by conservation biologist Peter Kareiva, espouses the view that conservation should primarily protect the interests of vulnerable human communities and sees the goal of 21st-century conservation as trying to "...maximize biodiversity without compromising development goals, such as energy and food production." (Kareiva, 2012) His approach would utilize ecosystem services, defined as those services that ecosystems provide for humans, as indicators of the effectiveness of conservation initiatives. (Daily et al., 2009)

The second, ecocentric perspective assumes that biodiversity loss is *morally* wrong, and that merely using people-centered motivation condemns species viewed as "useless" to extinction. Conservation biologist Reed Noss, a strong proponent of ecocentrism and the "Nature Needs Half" movement, would prefer indicators of conservation effectiveness that include the percentage of the earth that is designated as a protected area.(Kopnina et al., 2018)

The search for indicators of conservation effectiveness need not be limited to one or the other of these extreme positions. Humans and nature are interdependent, and disruption for any of the participants has potentially major impacts on the others. This would suggest that some system of indicators that included both a human and environmental metric would be the best choice for conservation practitioners.

A third and middle ground is represented by ecologist Michael Rosenzweig in his concept of "reconciliation ecology." (Rosenzweig, 2003) Rosenzweig argues that conservation science should focus on managing biodiversity in ways that do not decrease the human utility of the system, making it a "win-win" situation for both human land-use and ecosystem biodiversity. (Rosenzweig, 2003) This approach can be summarized as: "to be successful in the long run, any conservation effort simply must fold in the economic realities of the people living in or on the periphery of the real estate in question." (Eldredge, 2004; Winter 2004) In other words, both humans and natural systems are interdependent “patients” much like the pregnant mother and fetus. For local land-use decision-makers, this philosophical approach is appealing as it is the most likely to facilitate collaboration with private landowners to achieve conservation goals.

What properties indicate health-related quality of life for the conservation "patient"?: Every statistics professor at one time or another utters G. E. P. Box quote "All models are wrong, but some are useful" (Box, 1979) Current environmental conditions and biodiversity threats are creating an imperative for conservation science to maximize the effectiveness of interventions. The search for "perfect" indicators to model must stop impeding the use of "good" or even "not too bad" ones. Using Rosenzweig's idea of reconciliation ecology, a small number of indicators could be chosen at the start of a conservation project; some anthropocentric and some ecocentric. (Rosenzweig, 2003).

There are only rare examples of win-win studies in the literature, where the potential for both ecological restoration and improved human well-being are demonstrated. One such study was performed by Cao et al (2017) in rural China. Their ecocentric indicators were vegetation cover, soil erosion, and plant species number, and their anthropocentric indicators included net income, farmland area, and grazing restrictions.(Cao et al., 2019) Their evidence shows that there is a strong positive feedback loop between improvement of socio-economic indicators such as net income, with improvements in the indicators vegetation cover, soil erosion, and the number of plant species.

While the results demonstrate that win-win conservation is a viable concept, and the indicators relatively simple, the study was quite labor-intensive, requiring many hours of field and laboratory work.(Cao et al., 2017) This level of involvement by professional ecologists or conservation scientists would not be possible in the context of the large number of local conservation initiatives that are regularly implemented. Because the magnitude of the impact of an intervention is likely to depend on the site, species, intervention, and method of measurement, environmental evidence is likely to be more variable than evidence used in medicine (Smith et al., 2014). It will be necessary to collect data from a large number of different sites for the same intervention to fully implement a learning conservation system. Given the additional complexities as well as the scope and size of ecosystems, it might seem that achieving easily measured and reliable indicators of effectiveness in conservation science is too "wicked" of a problem to tackle; that is, too big to solve. (Laurance et al., 2012)

Can conservation science find simple and easy ways to collect data that can be rapidly analyzed to reflect effectiveness of their interventions? No matter how representative a set of indicators might be, they will not facilitate the development of a true learning conservation system if they can only be measured or analyzed by ecologists or conservation scientists - there are just not enough of them. In the learning healthcare system, medical data routinely collected as part of the normal patient encounter are combined with a questionnaire which is self-administered by patients, analyzed on site, and the results are implemented in successive patient encounters to improve care.

As in medicine, significant technological innovations and advancements have taken place over the past few decades in the collection of conservation science-relevant data. Because of this, the collection of ecological evidence for effectiveness need not be an insurmountable process. Considerable amounts of data are collected through the following sources: iIn situ and remote sensors, community data resources, biodiversity databases, permanent stations.(Farley et al., 2018)

Ecology is now considered a "big data" science based on the volume of data that is continuously generated by these sources. (Aubin et al., 2020) The extent and diversity of these data would suggest that a learning conservation system may be eminently possible. Conservation managers could use these data acquired through routine monitoring to guide future management actions (Conroy and Peterson, 2013). Big data has led to revolutionary advances in multiple fields but until recently has received limited attention in conservation. Online open data sources can be used to systematically identify species of high interest at global and regional scales, monitor temporal and spatial variations, and, in some cases, track the distribution and abundance of species. Big data are a valuable complement to existing conservation methods. Knowing how to access and interpret these data should be part of every conservationist's tool kit in the twenty-first century. (Mittermeier, 2020)

Without adequate groundtruthing, remote sensing data cannot be relied upon to provide usable evidence. The collection of biological information, particularly data gathered in the field, is essential to our understanding of how human impacts on biological systems can be recognized, mitigated or averted through effective conservation interventions. However, the proportion of fieldwork-based investigations in the conservation literature dropped significantly from the 1980s through 2014 and fieldwork-based publications decreased by 20% in comparison to a rise of 600% and 800% in modelling and data analysis studies. (Ríos-Saldaña et al., 2018) One reason for this change is thought to be pressure from policy-makers for rapid turnaround of research studies to inform decisions.(Ríos-Saldaña et al., 2018) Incorporating monitoring into conservation initiatives and using real-world evidence in a learning conservation system could provide the kind of information needed in a format appropriate to policy-making.

Another reason for the decrease in conservation science fieldwork is the pressure to publish; the most highly cited academic journals in conservation science published fieldwork studies less frequently than the lower rank journals. (Ríos-Saldaña et al., 2018) Thus, academic conservation scientists have a disincentive to perform fieldwork-based research. To perform the kind of monitoring required for a learning conservation system will require finding a large workforce - another part of the "wicked" problem.

Solving A "Wicked" Problem - Using What We Have to Build What We Need

There has never been a time during which it was more important to "think global and act local" from an environmental perspective. We must make our local conservation efforts as effective as possible. If we are to achieve the goal of evidence-based conservation, then we must arrive at a strategy to collect evidence of effectiveness. Medical science succeeded at establishing a comparative effectiveness framework and Learning Healthcare System through the use of real-world evidence based upon data that were already being collected and analyzing them in concert with patient reports of healthcare status a combination of automated and user-reported data. Added to this was a communication of the evidence to practitioners in a usable format establishing a method of feedback designed to improve future practice. The volume of data to be analyzed and the size of the necessary workforce needed to collect field data on the sheer number of conservation initiatives around the world is of such a size and complexity to be classified as a "wicked problem."

Figure 10: NASA engineers portrayed in the 1995 movie “Apollo 13” (Source: Universal Pictures)

To solve the “wicked problem” of evidence-based conservation, we may need to look to another scientific discipline; one with unique experience solving “wicked problems”. The image above from the movie *Apollo 13* depicts what has been called "The greatest space hack ever."[6] When an oxygen tank exploded as Apollo 13 neared the moon, the three-man crew had to abort their mission, power down the Command Module, and move into the Lunar Module for the journey home. Designed to house only two people, the craft quickly filled with dangerous levels of carbon dioxide. To save themselves, the astronauts had to somehow attach a square carbon dioxide scrubber to the circular opening of the Lunar Module's filtration system. The engineering team on the ground was forced to design an adapter from the limited items on board, including hoses from spacesuits, tube socks, and duct tape. The most challenging aspect was not how to do it, but how to do it with the materials they had on board and did not absolutely need in the spacecraft. The Apollo 13 solution can be described as the formulation of a solution to a critical problem utilizing only the resources that are readily at hand.

[6] Patel, 2014

Could an Apollo 13-type solution be used to facilitate the development and use of evidence in local conservation decision-making? In other words, can conservation scientists formulate a workable solution to the challenge of effective evidence-based decision making for those who make the majority of conservation decisions in the United States? Rather than attempting to identify the "perfect" solution to the problem, perhaps a more workable solution might be to begin with the resources that are available to local conservation practitioners.

The first step in the Apollo 13 process is to identify what resources we have that can be used to meet our goal. As described above, we have a wealth of data that is being collected continuously and compiled into databases and other digital records. Much of these data are publicly accessible. Another significant resource is the availability of labor in the form of citizen scientists; laypersons willing to volunteer time to collect real-world data for conservation.

Citizen Science

Citizen science is defined as a collaboration between scientists and non-scientists with concern, curiosity, and motivation to make a difference. It is used to refer to a collaboration between professionals and amateurs in scientific disciplines. The massive collaborations that can occur through citizen science allow investigations at continental and global scales and across decades.

Professional astronomers have long recognized how amateurs can help them with their research. Given the vastness of space, observational studies that are too time-consuming for professional astronomers to even consider undertaking themselves can be performed by groups of amateur observers. Occasionally, amateurs working on their own initiative, make important observations which can then be followed-up and validated by professionals. For example, in 2012, amateur astronomers were the first to spot impacts on Jupiter, with their observations then pursued using professional telescopes.(Malik, 2012)

Citizen science engages the public in ecological and conservation science projects that are too labor-intensive to be carried out solely by scientists who lack the resources to collect or analyze data on such a large scale. The term "citizen science" has begun to appear in peer-reviewed journals, which suggests that the term and concept is gaining wider acceptance (Follett and Strezov, 2015). However, the number of articles citing methodology and validation issues indicated that scientists are concerned that the data collected or analyzed may contain errors resulting from the use of untrained citizens. For citizen science to become a widely accepted scientific practice, data-quality issues need to be addressed and data collected by the public must be validated. (Dickinson et al., 2010)

While there is some concern that citizen-contributed data may be subject to quality issues such as imprecise spatial position and biased spatial coverage, these issues are not insurmountable. Geovisualization and geospatial analysis capabilities that are provided by geographic information systems (GISs) can address data quality issues as will be shown in the following demonstration project. (Zhang, 2019)

A Demonstration Project: Effectiveness of Coastal Erosion Management Strategies Using Win-Win Indicators for Landowners and Piping Plovers, *Charadrius melodus*

Demonstration Study Results:

Variability of shoreline: There is historical evidence that the shape of the mapped shoreline has been changed by the placement of man-made erosion control structures in the past. Figure 11 shows a plot of historic shoreline position between 1844 - 2009 along a stretch of beach between Breakwater Landing and Point of Rocks showing the change over time in the mean high water level. Between 1830 and 1870, a large breakwater was built and maintained offshore from Breakwater Landing creating a safe harbor for Brewster sea captains to be transported by packet boat to their clipper ships anchored in deep water.[7] The destruction of this breakwater is reflected in the changes between the red and orange lines on the map below. The placement of multiple perpendicular groins in the 1950s caused in response to the beach loss resulted in accretion on the west side of the groins and sand removal on the east side due to interrupted longshore drift. Based on historical photographs, changes were visible in the dunes as soon as two years after the groins were placed.

[7] Personal Communication Brewster Town Historian Sally Cabot Gunning (April, 2020)

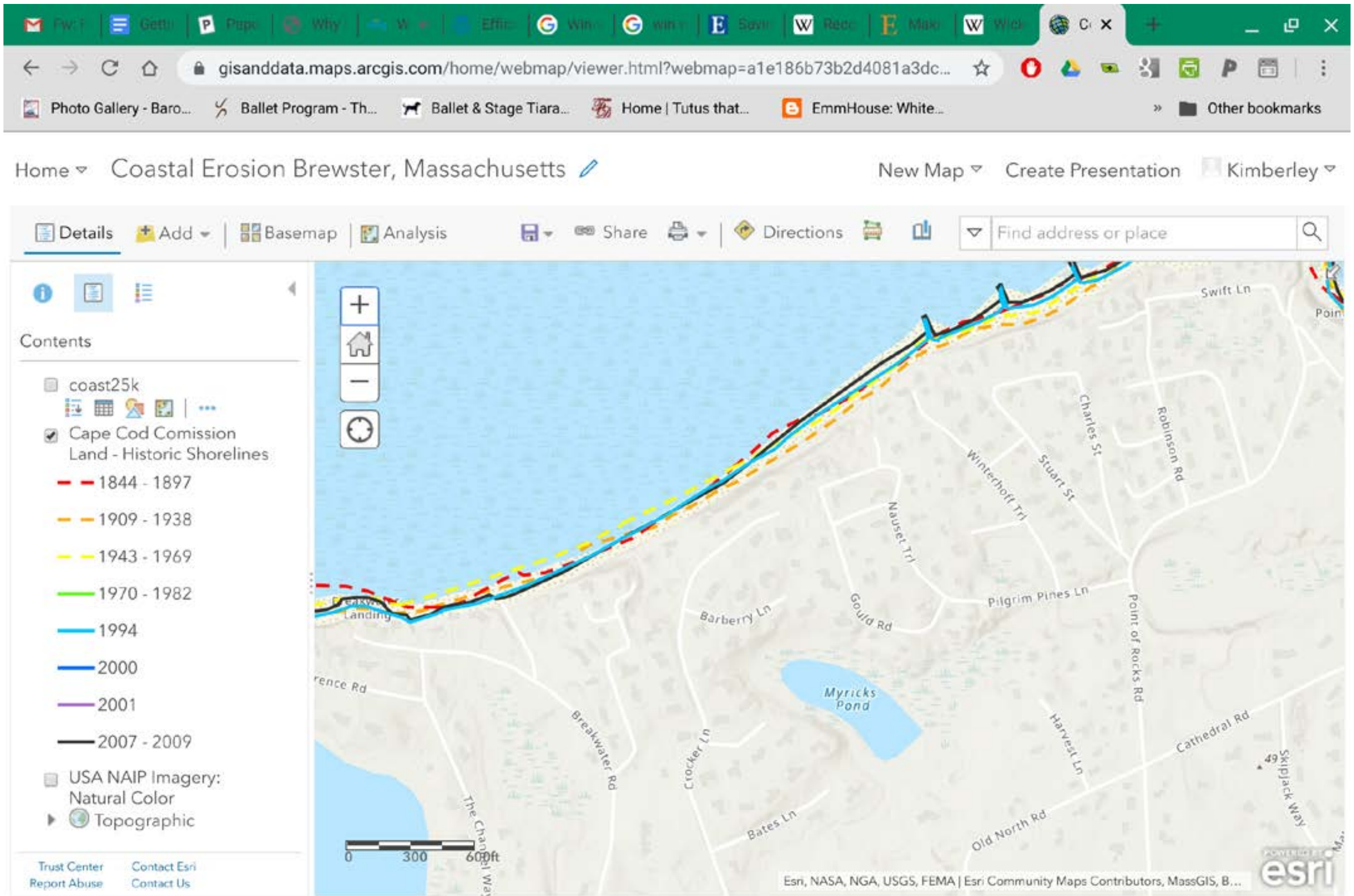


Figure 11: This image depicts Historical Shoreline Position, Brewster, Massachusetts
Source: Cape Cod Commission GIS LIbrary

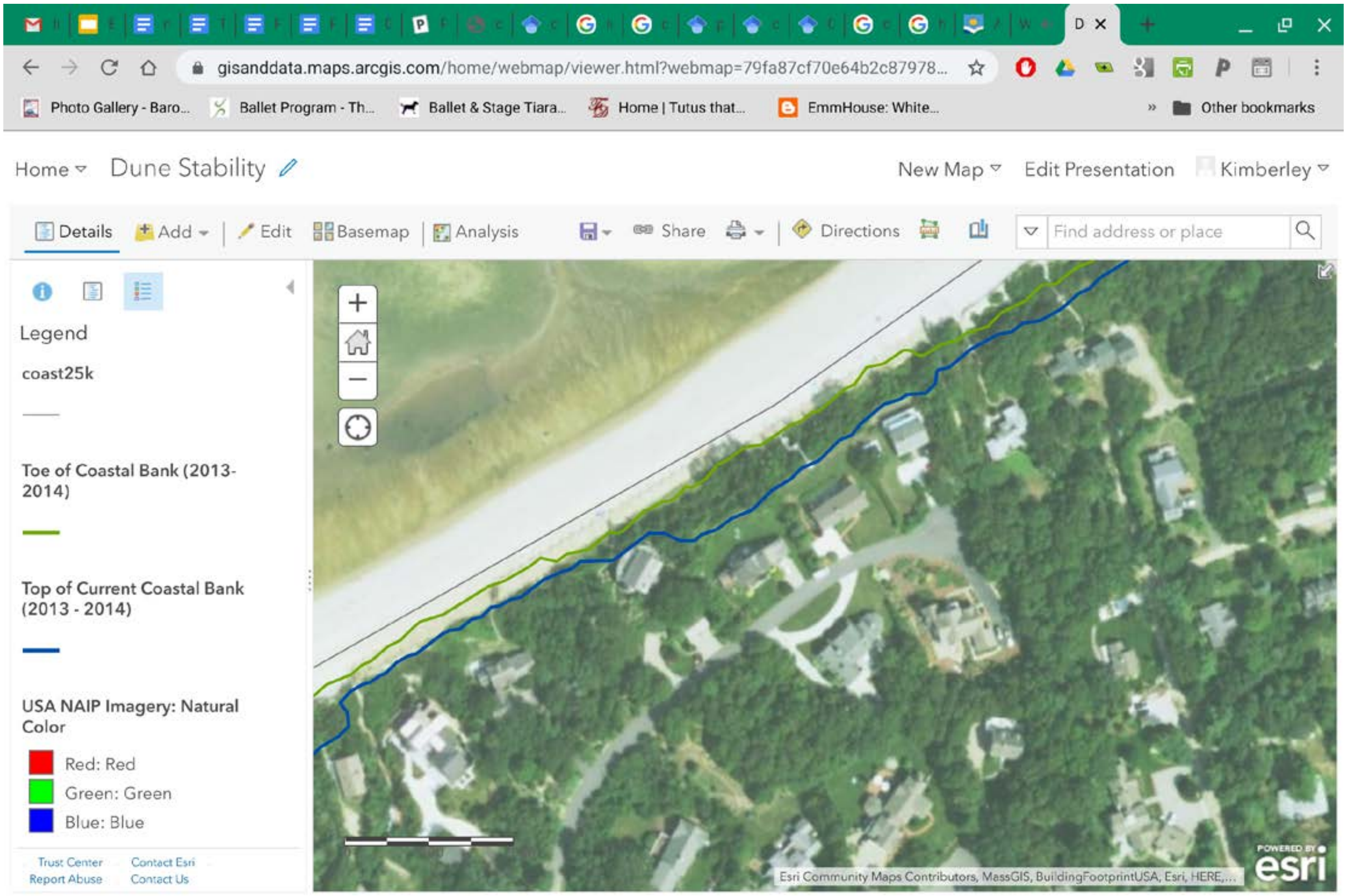


Figure 12: This image depicts the top (blue line) and toe (green line) of the coastal bank between Breakwater Landing to Point of Rocks, Brewster, Massachusetts. Also shown is the mean high water line (coast 25K) Source: Massachusetts GIS Library

The effectiveness of erosion technologies from the landowner's perspective is stabilization of the coastal dune. This can be measured by mapping the position of the top and toe of the dune over time, as depicted in Figure 12. These indicators are routinely collected by the Cape Cod Commission and are publicly available on their website.[8] Over the next few years, new data will be added to this map and any changes in the extent and position of the coastal dune will be noted.

[8] https://www.capecodcommission.org/our-work/gis-open-data-hub/

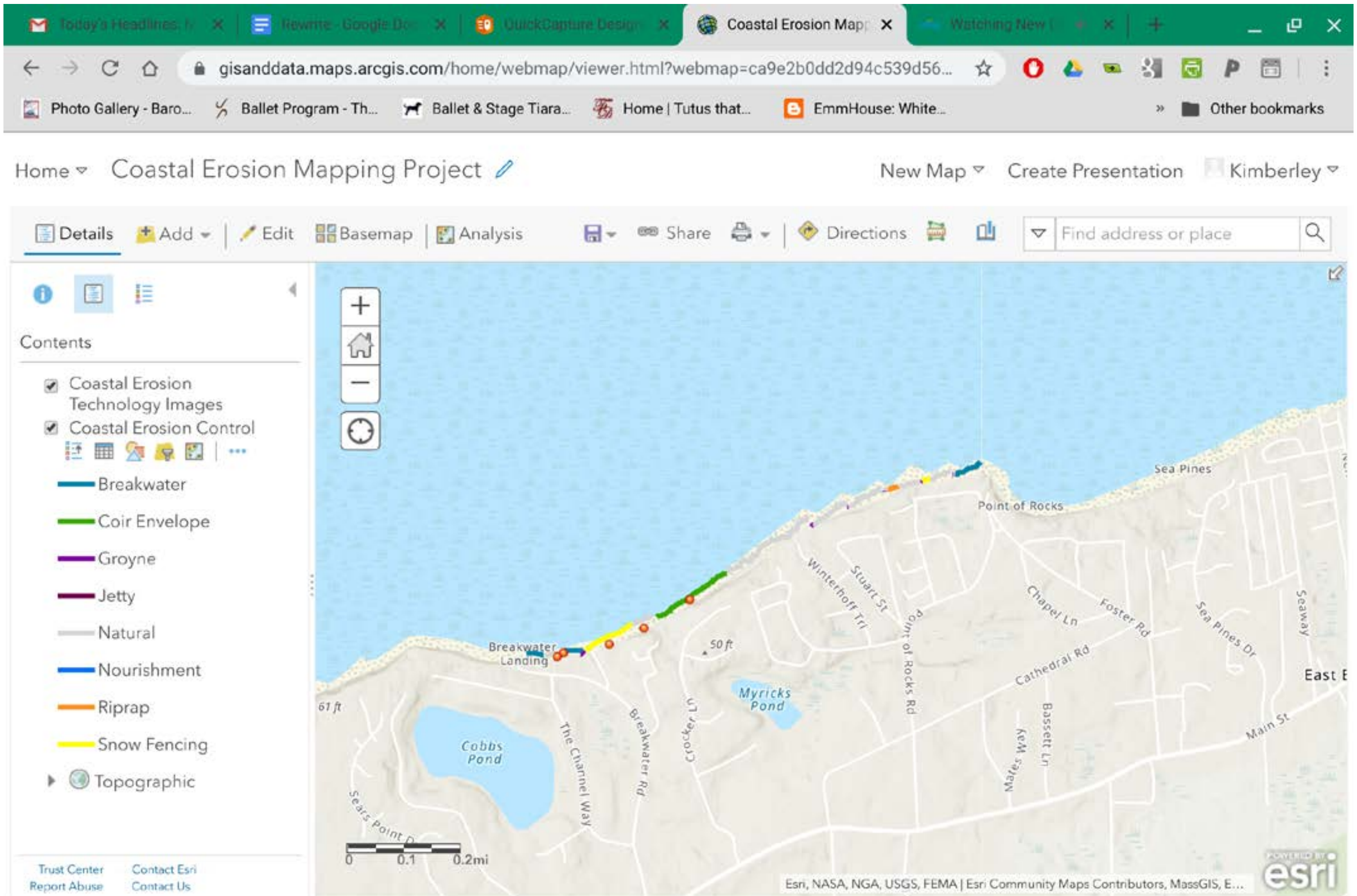


Figure 13: On the map pictured here, the volunteer mapping data are represented by the thick colored lines running parallel to the shore. The perpendicular yellow lines represent shoreline change transects measured biennially.

The compiled data from the volunteer mapping are shown in Figure 13. Because erosion technologies can be upgraded or removed, this mapping will need to be repeated annually. Ultimately, changes in the extent and position of the coastal dune will be compared with the type of erosion technology to determine comparative effectiveness.

While its association with the dune restoration is unknown, a single Piping Plover nest scrape was observed in the new grass plantings above one of the coir envelopes.

Figure 14: Piping Plover nest scraping Brewster, Massachusetts Dunes between Breakwater Landing and Point of Rocks

Discussion

The purpose of the mapping project was to demonstrate that the collection of effectiveness data for conservation initiatives could be performed fairly easily at the local level. All of the GIS data were available from MassGIS or the Cape Cod Commission. The QuickCapture app is based on the online ArcGIS platform and can be transmitted to volunteers through the use of a QR code. Conservation scientists would be able to set up and test the methodology and analyze the incoming data, but the majority of data collection would be done by volunteers. Data on beach erosion from the GIS libraries will be added every two years or sooner depending on the strength of the storm season.

At the time of this data collection, only one Plover nest scraping was observed on the Brewster dunes. The scraping was photographed and geocoded onto the map. These birds generally nest in less populous areas than the Brewster beaches so the significance of this sighting is interesting but not overly significant at this time.

The validity of the collected data was high as there were no discrepancies among the volunteer observations. Each volunteer worked independently and there were no problems expressed with the operation of the app. All volunteers lived locally and thus were familiar with the beach and the erosion control technology. None were property owners on the shore.

The basics of the study along with the concept of "win-win" indicators were informally discussed with local Conservation Commission members during the project. There was general enthusiasm for such outcome indicators, the feeling being that mandating shared benefits between humans and biodiversity would be better accepted by private landowners than those that seemed only for the benefit of "nature." There was also a very positive response to the possibility of receiving feedback on the conservation impacts of land-use decisions being made by the Commission. There was a consensus that interactions with land-owners and their attorneys would be facilitated by comparative effectiveness data on the more ecological erosion control measures.

Conclusion

Conservation Science must continue to follow the lead of medical science by adopting the collection of real-world evidence of effectiveness as a routine part of studies. The demonstration study, herein described, shows the ease with which comparative effectiveness data could be measured using readily available resources. Measurements of effectiveness that utilize "win-win" indicators are likely to be best received in the local conservation setting where it is often necessary to convince private landowners to do the "right thing" from a conservation perspective while satisfying their desire to adapt the land-use parameters of their property.

When designing studies that involve citizen scientists, conservation scientists must consider validity and bias controls. Methodologies that can be used, such as duplication of observations, as was used in this demonstration study can increase the validity of data and minimize bias.

Ultimately, effectiveness data must be a required part of conservation research as they have become in medicine. The challenge of developing a true generic indicator set like the EQ-5D for conservation initiatives is complicated by the tremendous variability among ecosystem types and disagreement among conservation scientists as to the best perspective through which to view biodiversity. Again, it is worth turning to medicine for guidance. Not all view the quality of life indicators and their valuation in the EQ-5D as the "best" indicators. For example, the disability community strongly objects to questions of mobility as determining factors for quality of life. (Taylor et al., 2001) It is similarly unlikely that conservation science will find perfect generic indicators but local land-use decision-makers look forward to having effectiveness data to further their adaptive management of the ecosystems in their care.

Acknowledgement

I would like to acknowledge the generous support of the Brewster Conservation Trust, the Cape Cod Commission, Coastal Commission, and the Brewster Conservation Commission.

This project would not have been possible without the mentorship of Dr. Jorge Santiago-Blay. Dr. Blay epitomizes the ethos of the true scientist by holding himself and his students to the highest standards of scholarship, rigorous investigation, and thoughtful, honest appraisal of our work.

References Cited

10th Amendment US Constitution--Reserved Powers. https://www.govinfo.gov/content/pkg/GPO-CONAN-1992/pdf/GPO-CONAN-1992-10-11.pdf

Abernethy, A. P., Ahmad, A., Zafar, S. Y., Wheeler, J. L., Reese, J. B., & Lyerly, H. K. (2010). Electronic patient-reported data capture as a foundation of rapid learning cancer care. *Medical Care*, *48*(6 Suppl), S32–S38. https://doi.org/10.1097/MLR.0b013e3181db53a4

Arlettaz, R., Schaub, M., Fournier, J., Reichlin, T. S., Sierro, A., Watson, J. E. M., & Braunisch, V. (2010). From Publications to Public Actions: When Conservation Biologists Bridge the Gap between Research and Implementation. *Bioscience*, *60*(10), 835–842. https://doi.org/10.1525/bio.2010.60.10.10

Aubin, I., Cardou, F., Boisvert-Marsh, L., Garnier, E., Strukelj, M., & Munson, A. D. (2020). Managing data locally to answer questions globally: the role of collaborative science in ecology. *Journal of Vegetation Science: Official Organ of the International Association for Vegetation Science*. https://doi.org/10.1111/jvs.12864

Audubon. (2018). “Piping Plover.” In Audubon (Ed.), *Coastal Bird Stewardship Toolkit*. www.audubon.org/fieldguide/bird/piping-plover

Boardman, P. (1978). *The worlds of Patrick Geddes: biologist, town planner, re-educator, peace-warrior*. Routledge.

Box, G. E. P. (1979). All models are wrong, but some are useful. *Robustness in Statistics*, *202*, 549. https://www.actuaries.org.uk/documents/d05-economic-capital-model-validation-process-and-technical-guidelines

Brewer, G. D., & Stern, P. C. (2005). *Decision making for the environment: Social and* *behavioral science research priorities*. National Academies Press Washington, DC. https://pdfs.semanticscholar.org/8809/934f283101f0739f28337f1a85156f6e398d.pdf

Cao, Q., Zhang, X., Lei, D., Guo, L., Sun, X., Kong, F. 'en, & Wu, J. (2019). Multi-scenario simulation of landscape ecological risk probability to facilitate different decision-making preferences. *Journal of Cleaner Production*, *227*, 325–335. https://doi.org/10.1016/j.jclepro.2019.03.125

Cao, S., Shang, D., Yue, H., & Ma, H. (2017). A win-win strategy for ecological restoration and biodiversity conservation in Southern China. *Environmental Research Letters: ERL [Web Site]*, *12*(4), 044004. https://doi.org/10.1088/1748-9326/aa650c

Corrigan-Curay, J., Sacks, L., & Woodcock, J. (2018). Real-World Evidence and Real-World Data for Evaluating Drug Safety and Effectiveness. *JAMA: The Journal of the American Medical Association*, *320*(9), 867–868. https://doi.org/10.1001/jama.2018.10136

Daily, G. C., Polasky, S., Goldstein, J., Kareiva, P. M., Mooney, H. A., Pejchar, L., Ricketts, T. H., Salzman, J., & Shallenberger, R. (2009). Ecosystem services in decision making: time to deliver. *Frontiers in Ecology and the Environment*, *7*(1), 21–28. https://doi.org/10.1890/080025

Deeny, S. R., & Steventon, A. (2015). Making sense of the shadows: priorities for creating a learning healthcare system based on routinely collected data. In *BMJ Quality & Safety* (Vol. 24, Issue 8, pp. 505–515). https://doi.org/10.1136/bmjqs-2015-004278

Devlin, N. J., & Brooks, R. (2017). EQ-5D and the EuroQol Group: Past, Present and Future. *Applied Health Economics and Health Policy*, *15*(2), 127–137. https://doi.org/10.1007/s40258-017-0310-5

Dickinson, J. L., Zuckerberg, B., & Bonter, D. N. (2010). Citizen Science as an Ecological

Research Tool: Challenges and Benefits. *Annual Review of Ecology, Evolution, and Systematics*, *41*(1), 149–172. https://doi.org/10.1146/annurev-ecolsys-102209-144636

Dicks, L. V., Walsh, J. C., & Sutherland, W. J. (2014). Organising evidence for environmental management decisions: a “4S”hierarchy. *Trends in Ecology & Evolution*, *29*(11), 607–613. https://www.sciencedirect.com/science/article/pii/S0169534714001992

Djulbegovic, B., & Guyatt, G. H. (2017). Progress in evidence-based medicine: a quarter century on. *The Lancet*, *390*(10092), 415–423. https://doi.org/10.1016/S0140-6736(16)31592-6

Eldredge, N. (2004///Winter2004). Saving species. *Issues in Science and Technology*, *20*(2), 90. http://search.ebscohost.com/login.aspx?direct=true&db=f5h&AN=12061579&site=ehost-live&scope=site

Evidence-Based Medicine Working Group. (1992). Evidence-based medicine. A new approach to teaching the practice of medicine. *JAMA: The Journal of the American Medical Association*, *268*(17), 2420–2425. https://doi.org/10.1001/jama.1992.03490170092032

Farley, S. S., Dawson, A., Goring, S. J., & Williams, J. W. (2018). Situating Ecology as a Big-Data Science: Current Advances, Challenges, and Solutions. *Bioscience*, *68*(8), 563–576. https://doi.org/10.1093/biosci/biy068

Ferraro, P. J., & Pattanayak, S. K. (2006). Money for nothing? A call for empirical evaluation of biodiversity conservation investments. *PLoS Biology*, *4*(4), e105. https://doi.org/10.1371/journal.pbio.0040105

Follett, R. and Strezov, V. (2015) An Analysis of Citizen Science Based Research: Usage and Publication Patterns. PLoS ONE 10(11): e0143687. doi:10.1371/journal.pone.0143687

Forrest, C. B., Margolis, P. A., Bailey, L. C., Marsolo, K., Del Beccaro, M. A., Finkelstein, J. A., Milov, D. E., Vieland, V. J., Wolf, B. A., Yu, F. B., & Kahn, M. G. (2014). PEDSnet: a

National Pediatric Learning Health System. In *Journal of the American Medical Informatics Association* (Vol. 21, Issue 4, pp. 602–606). https://doi.org/10.1136/amiajnl-2014-002743

Gilbert, R., Salanti, G., Harden, M., & See, S. (2005). Infant sleeping position and the sudden infant death syndrome: systematic review of observational studies and historical review of recommendations from 1940 to 2002. *International Journal of Epidemiology*, *34*(4), 874–887. https://doi.org/10.1093/ije/dyi088

Godet, L., & Devictor, V. (2018). What Conservation Does. *Trends in Ecology & Evolution*, *33*(10), 720–730. https://doi.org/10.1016/j.tree.2018.07.004

Guyatt, G. (1991). Evidence-Based Medicine. *ACP Journal Club*, *A-16*, 114. https://doi.org/10.7326/0003-4819-114-2-165

Hayward, M. W., Callen, A., Allen, B. L., Ballard, G., Broekhuis, F., Bugir, C., Clarke, R. H., Clulow, J., Clulow, S., Daltry, J. C., Davies-Mostert, H. T., Fleming, P. J. S., Griffin, A. S., Howell, L. G., Kerley, G. I. H., Klop-Toker, K., Legge, S., Major, T., Meyer, N., … Wüster, W. (2019). Deconstructing compassionate conservation. *Conservation Biology: The Journal of the Society for Conservation Biology*, *33*(4), 760–768. https://doi.org/10.1111/cobi.13366

Jenkins, C. N., Van Houtan, K. S., Pimm, S. L., & Sexton, J. O. (2015). US protected lands mismatch biodiversity priorities. *Proceedings of the National Academy of Sciences of the United States of America*, *112*(16), 5081–5086. https://doi.org/10.1073/pnas.1418034112

Kaefer, M., Castagnetti, M., Herbst, K., Bagli, D., Beckers, G. M. A., Harper, L., Kalfa, N., Fossum, M., & ESPU Research Committee. (2019). Evidence-based medicine III: level of evidence. *Journal of Pediatric Urology*, *15*(4), 407–408. https://doi.org/10.1016/j.jpurol.2019.04.012

Kareiva, P. M. (2012). QnAs with Peter M. Kareiva. *Proceedings of the National Academy of*

Sciences of the United States of America, *109*(26), 10127. https://doi.org/10.1073/pnas.1207920109

Karimi, M., & Brazier, J. (2016). Health, Health-Related Quality of Life, and Quality of Life: What is the Difference? *PharmacoEconomics*, *34*(7), 645–649. https://doi.org/10.1007/s40273-016-0389-9

Kim, S. Y. (2013). Efficacy versus Effectiveness. *Korean Journal of Family Medicine*, *34*(4), 227. https://doi.org/10.4082/kjfm.2013.34.4.227

Kopnina, H. (2017.). *Anthro versus Ecocentric Conservation Perspectives: An Academic Comparison | Voices for Biodiversity*. Voices for Biodiversity. Retrieved April 13, 2020, from https://voicesforbiodiversity.org/articles/anthro-versus-ecocentric-conservation-perspectives

Kopnina, H., Washington, H., Gray, J., & Taylor, B. (2018). "The 'future of conservation' debate: Defending ecocentrism and the Nature Needs Half movement." *Biological Conservation*, *217*, 140–148. https://doi.org/10.1016/j.biocon.2017.10.016

Lager, D.N. (2016, October 24). *Hard vs. Soft Solutions for Coastal Erosion | Mid Atlantic Real Estate Journal*. Marejournal; Mid Atlantic Real Estate Journal. https://www.marejournal.com/single-post/2016/10/24/Hard-vs-Soft-Solutions-for-Coastal-Erosion

Lancaster, J. (2000). The ridiculous notion of assessing ecological health and identifying the useful concepts underneath. *Human and Ecological Risk Assessment: An International Journal*, *6*(2), 213–222. https://doi.org/10.1080/10807030009380056

Laurance, W. F., Koster, H., Grooten, M., Anderson, A. B., Zuidema, P. A., Zwick, S., Zagt, R. J., Lynam, A. J., Linkie, M., & Anten, N. P. R. (2012). Making conservation research more relevant for conservation practitioners. *Biological Conservation*, *153*, 164–168. https://doi.org/10.1016/j.biocon.2012.05.012

Logan, M., Hu, Z., Brinkman, R., Sun, S., Sun, X., & Schaffelke, B. (2020). Ecosystem health report cards: An overview of frameworks and analytical methodologies. *Ecological Indicators*, *113*, 105834. https://doi.org/10.1016/j.ecolind.2019.105834

Lutz, H. J., Costello, D. F., Hickie, P., Stone, E. L., Bates, M., & Ellison, L. (1957). Symposium on Applications of Ecology. *Ecology*, *38*(1), 46–64. https://doi.org/10.2307/1932125

Maestre A S., Calvet M., L., van den Bergh, J. C. J. M., Ring, I., & Verburg, P. H. (2012). Ineffective biodiversity policy due to five rebound effects. *Ecosystem Services*, *1*(1), 101–110. https://doi.org/10.1016/j.ecoser.2012.07.003

Malik, T (2012). Explosive Impact at Jupiter Spotted by Amateur Astronomers. *Scientific American*. https://www.scientificamerican.com/article/explosive-impact-at-jupiter-spotted-by-amateur-astronomers/

Marmorek, D., Nelitz, M., Eyzaguirre, J., Murray, C., & Alexander, C. (2019). Adaptive Management and Climate Change Adaptation: Two Mutually Beneficial Areas of Practice. *Journal of the American Water Resources Association*, *55*(4), 881–905. https://doi.org/10.1111/1752-1688.12774

Mittermeier, J. C. (2020). *Species conservation in the era of digital big data* [University of Oxford]. https://ethos.bl.uk/OrderDetails.do?uin=uk.bl.ethos.800175

Moon, K. (2011). Conservation on Private Land. PhD thesis, James Cook University. *Pdfs.semanticscholar.org*. https://pdfs.semanticscholar.org/3c61/b48f7e97179d02994e431a677141648f3520.pdf

Mullins, C. D., Wingate, L. T., Edwards, H. A., Tofade, T., & Wutoh, A. (2018). Transitioning from learning healthcare systems to learning health care communities. *Journal of Comparative Effectiveness Research*, *7*(6), 603–614. https://doi.org/10.2217/cer-2017-0105

Munasinghe, M., & Shearer, W. (1995). *Defining and measuring sustainability: the biogeophysical foundations*. International Bank for Reconstruction and Development, Washington, DC …. https://www.osti.gov/biblio/108040

Porter, D. R. (2012). *Managing Growth in America's Communities: Second Edition*. Island Press. https://play.google.com/store/books/details?id=7jG2qHCs8EgC

Pullin, A. S. (2015). *Why is the evidence base for effectiveness of win–win interventions to benefit humans and biodiversity so poor?* https://link.springer.com/article/10.1186/s13750-015-0045-4

Pullin, A. S., & Knight, T. M. (2001). Effectiveness in Conservation Practice: Pointers from Medicine and Public Health. *Conservation Biology: The Journal of the Society for Conservation Biology*, *15*(1), 50–54. https://doi.org/10.1111/j.1523-1739.2001.99499.x

Pullin, A. S., & Knight, T. M. (2003). Support for decision making in conservation practice: an evidence-based approach. *Journal for Nature Conservation*, *11*(2), 83–90. https://doi.org/10.1078/1617-1381-00040

Pullin, A. S., & Knight, T. M. (2005). Assessing Conservation Management's Evidence Base: A Survey of Management-Plan Compilers in the United Kingdom and Australia. *Conservation Biology: The Journal of the Society for Conservation Biology*, *19*(6), 1989–1996. https://doi.org/10.1111/j.1523-1739.2005.00287.x

Pullin, A. S., Knight, T. M., Stone, D. A., & Charman, K. (2004). Do conservation managers use scientific evidence to support their decision-making? *Biological Conservation*, *119*(2), 245–252. https://doi.org/10.1016/j.biocon.2003.11.007

Rannap, R., Lõhmus, A., & Briggs, L. (2010). Restoring ponds for amphibians: a success story. In B. Oertli, R. Céréghino, J. Biggs, S. Declerck, A. Hull, & M. R. Miracle (Eds.), *Pond Conservation in Europe* (pp. 243–251). Springer Netherlands. https://doi.org/10.1007/978-90-481-9088-1_20

Rapport, D. J., Regier, H. A., & Hutchinson, T. C. (1985). Ecosystem Behavior Under Stress. *The American Naturalist*, *125*(5), 617–640. https://doi.org/10.1086/284368

Räsänen, P., Roine, E., Sintonen, H., Semberg-Konttinen, V., Ryynänen, O.-P., & Roine, R. (2006). Use of quality-adjusted life years for the estimation of effectiveness of health care: A systematic literature review. *International Journal of Technology Assessment in Health Care*, *22*(2), 235–241. https://doi.org/10.1017/S0266462306051051

Ríos-Saldaña, C. A., Delibes-Mateos, M., & Ferreira, C. C. (2018). Are fieldwork studies being relegated to second place in conservation science? *Global Ecology and Conservation*, *14*, e00389. https://doi.org/10.1016/j.gecco.2018.e00389

Rosenzweig, M. L., & Michael L. (Professor of Ecology and Evolutionary Biology Rosenzweig, University of Arizona). (2003). *Win-win Ecology: How the Earth's Species Can Survive in the Midst of Human Enterprise*. Oxford University Press. https://play.google.com/store/books/details?id=8mvnCwAAQBAJ

Schiller, A., Hunsaker, C., Kane, M., Wolfe, A., Dale, V., Suter, G., Russell, C., Pion, G., Jensen, M., & Konar, V. (2001). Communicating Ecological Indicators to Decision Makers and the Public. *Conservation Ecology*, *5*(1). https://doi.org/10.5751/ES-00247-050119

Smith, R. K., Dicks, L. V., Mitchell, R., & Sutherland, W. J. (2014). Comparative effectiveness research: the missing link in conservation. *Conservation Evidence*, *11*, 2–6. https://www.researchgate.net/profile/William_Sutherland/publication/287953350_Comparat ive_effectiveness_research_The_missing_link_in_conservation/links/567e5b1108ae197583 88bf4a.pdf

Smith, R., & Rennie, D. (2014). Evidence based medicine--an oral history. *BMJ* , *348*, g371. https://doi.org/10.1136/bmj.g371

Sodhi, N. S., Butler, R., Laurance, W. F., & Gibson, L. (2011). Conservation successes at micro-, meso- and macroscales. *Trends in Ecology & Evolution*, *26*(11), 585–594. https://doi.org/10.1016/j.tree.2011.07.002

Soulé, M. E. (1985). What Is Conservation Biology? *Bioscience*, *35*(11), 727–734. https://doi.org/10.2307/1310054

Sutherland, W. J., Pullin, A. S., Dolman, P. M., & Knight, T. M. (2004). The need for evidence-based conservation. *Trends in Ecology & Evolution*, *19*(6), 305–308. https://doi.org/10.1016/j.tree.2004.03.018

Sutherland, W. J., Taylor, N. G., MacFarlane, D., Amano, T., Christie, A. P., Dicks, L. V., Lemasson, A. J., Littlewood, N. A., Martin, P. A., Ockendon, N., Petrovan, S. O., Robertson, R. J., Rocha, R., Shackelford, G. E., Smith, R. K., Tyler, E. H. M., & Wordley, C. F. R. (2019). Building a tool to overcome barriers in research-implementation spaces: The Conservation Evidence database. *Biological Conservation*, *238*, 108199. https://doi.org/10.1016/j.biocon.2019.108199

Swift, B., Jain, L., White, C., Chandrasekaran, V., Bhandari, A., Hughes, D. A., & Jadhav, P. R. (2018). Innovation at the intersection of clinical trials and real-world data science to advance patient care. *Clinical and Translational Science*, *11*(5), 450–460. https://ascpt.onlinelibrary.wiley.com/doi/abs/10.1111/cts.12559

Taylor, P. (2008). *From Patient Data to Medical Knowledge: The Principles and Practice of*

Health Informatics. John Wiley & Sons. https://play.google.com/store/books/details?id=Tr7v3K_MJdMC

Taylor, W. J., Lord, S., McPherson, K. M., & McNaughton, H. K. (2001). EuroQol EQ-5D may not adequately describe the health of people with disabilities. *Disability and Rehabilitation*, *23*(7), 281–285. https://doi.org/10.1080/096382801750143607

Theobald, D. M., Hobbs, N. T., Bearly, T., Zack, J. A., Shenk, T., & Riebsame, W. E. (2000). Incorporating biological information in local land-use decision making: designing a system for conservation planning. *Landscape Ecology*, *15*(1), 35–45. https://doi.org/10.1023/A:1008165311026

Vincent, C. H., Hanson, L. A., & Argueta, C. N. (2017). *Congressional Research Service 2017 Federal Land Ownership: Overview and Data*.

Wahl, D. C. (2017). *Design and Planning for People in Place: Sir Patrick Geddes (1854–1932) and the Emergence of…*. Medium; Medium. https://medium.com/@designforsustainability/design-and-planning-for-people-in-place-sir-patrick-geddes-1854-1932-and-the-emergence-of-2efa4886317e

Wang, L. and Bush, S. (2018). Piping Plover Habitats: How Have They Changed Over Time (1971-2005) and Where Do They Need the Most Protection in the Future? DOI: 10.13140/RG.2.2.25510.63040/1

West, S., Beilin, R., & Wagenaar, H. (2019). Introducing a practice perspective on monitoring for adaptive management. *People and Nature*, *1*(3), 387–405. https://doi.org/10.1002/pan3.10033

Zhang, G. (2019). Integrating Citizen Science and GIS for Wildlife Habitat Assessment. In M. Ferretti (Ed.), *Wildlife Population Monitoring*. IntechOpen.

https://doi.org/10.5772/intechopen.83681